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Research Article

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A symbolic dynamics approach to complexity analysis of concrete deformation based on wavelet de-noising

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ABSTRACT

The study approach of RCC(roller compacted concrete) autogenously volume deformation complexity based on the de-noising of wavelet transform from symbolic dynamics viewpoint is present in the paper. First, the deformation sequences are de-noised by the wavelet transform and the noise is filtered. Then the complexity of deformation is calculated with the Lempel-Ziv algorithm. Finally the complexity of RCC volume deformation is quantitatively analyzed in the practical engineering, and a new tool is provided to study the complexity of concrete system. The results are as following: (1) the complexity with wavelet de-noising is less than original sequence and has evident law. (2) the deformation complexity of high volume fly-ash slag RCC is markedly larger than that of RCC mixed with MgO.(3) the deformation complexity of early age RCC is higher than that of 180d. (4) The complexity is greater along with the higher temperature. (5) The deformation complexity of RCC mixed with air-entraining agent is greater.

Key words: Roller compacted concrete, autogenous volume deformation, complexity, wavelet transform, de-noising, symbolic dynamics

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INTRODUCTION

The autogenously volume deformation of concrete was mainly due to the density difference between reagents and products after the reaction between cementing materials and water. The volume showed expansion when product density is less than the density of reactants; on the contrary it showed contraction when density of reactants is less than the product density. When the expansion is excessive, it is equivalent with the deformation caused by dozens degree's temperature change, which illuminated that concrete volume deformation has an affect not to be ignored for the cracking problem[1].

The autogenously volume deformation of concrete is a complex dynamic system, including early drying shrinkage, plastic deformation, chemical deformation. When deformation system has an evolution from the normal cycle to random change, the complexity measurement of dynamic system changes significantly, through the complexity of the diagnosis we can measure the signal of deformation sequence; but it has not been reported for application of complexity theory in concrete deformation. As the complexity and fractal dimension are characterized by the token of fine structure in theory, and complexity and the measurement of fractal dimension almost have the same effect, further more the calculation of complexity is simple and data is small, so it has a higher value in engineering projects. The study approach of RCC autogenously volume deformation complexity based on the de-noising of wavelet transform from symbolic dynamics viewpoint is present in the paper. First, the deformation sequences are de-noised by the wavelet transform and the noise is filtered. Then the complexity of deformation is calculated with the Lempel-Ziv algorithm. Finally the complexity of RCC volume deformation is quantitatively analyzed in the practical engineering.

WAVELET TRANSFORM AND DENOISING

wavelet transform: For time series of deformation $X(t) \in L^2(R)$,the continuous wavelet transform is defined as[2]:

$$W_x(a,b) = |a|^{\frac{1}{2}} \int_{-\infty}^{+\infty} X(t)\psi\left[\frac{t-b}{a}\right]dt$$

（1）

In formula, $\psi(t)$ is mother wavelet, and meet condition of admissibility, that is complex $\int_{-\infty}^{+\infty} \psi(t)dt = 0$。$\psi(t)$ is conjugate function; a is scaling factor; b is time translation factor; $W_x(a,b)$ is Wavelet transform coefficient. $W_x(a,b)$ can also reflect the characteristic of time-domain parameter b and frequency domain parameter a , it is time series $X(t)$'s output by the filter of unit impulse response. When a is small, the resolution of frequency domain is low, and the resolution of time domain is high; When a becomes bigger, the resolution of frequency domain is high, and the resolution of time domain is low. Therefore, the wavelet transform can make time frequency localize, time frequency have fixed size and variable shape.

Wavelet de-noising: Because of observational reasons and many factors influence, deformation sequence contains noise. Generally, the useful signal is a low frequency signal or some stable signals, and that the noise is usually is high-frequency signals. Because the wavelet transform have multiresolution, it is able to decompose the signal into different frequency signals. Therefore, the wavelet can be used for signal de-noising and it is superior to the average sliding and Fourier law.

Rules of threshold selection

Signal $x(t) = \int(t) + e(t)$. In the formula, $\int(t)$ are useful signals; $e(t)$ is noise signal. In the de-noising process, there are three principle of threshold selection: (a) based on Stein unbiased Likelihood Estimation. (b) the fixed threshold value. (c) choose threshold According to the max and min principle. Each of three methods has shortcoming. Sample 2R6 deformation's Stein Soft threshold de-noising result is shown as Figure 1.

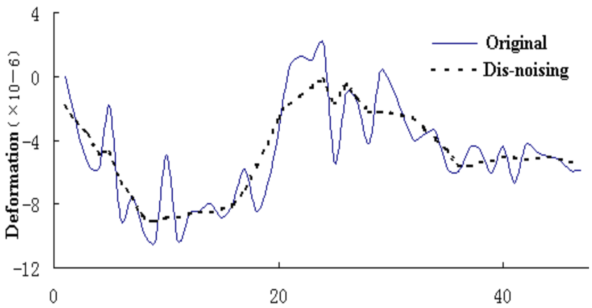


Fig 1 Deformation sequence and its de-noising sequences based on wavelet analysis of 2R6

COMPLICACY DIAGNOSTIC

Complicacy measurement: Kolmogorov gave a definition: a given character string complicacy measurement is equal to this character string's the shortest bytes number of computer program[3]. Lempel and Ziv. J proposed that it is feasible not to calculate the shortest bytes number of character string and use two simple operations, which is replication and insert as a procedure length's useful measurement number C_0 . This number is called as algorithm complicacy measurement, and complexity of the algorithm for short. The complexity of the algorithm C_0 is a stochastic measure reflecting the level of sequence close to random[4].

Factors of L-Z complexity: The symbols number in the symbolization of original sequence: according to symbol dynamics, the symbolization of 01 sequence is the roughest conversion for the original sequence. To study the number of symbols impact on the description of original sequence character, it is necessary to make symbolic dynamics description for partial subdivision of sequence.

The threshold choice in the symbolization: according to the definition of L-Z algorithm, Threshold choice is pivotal in the symbolization of original sequence. The average thresholds of sequence are selected in generic literature. This study will use the different thresholds.

The length of the sequence: there will inevitably require a certain length of sequence to express the complexity of sequence, and the length of the sequence should be chosen in terms of characteristic integrality and complicacy calculation.

COMPLEXITY OF DEFORMATION

The mix proportions of experiment: This study is a RCC performance test in a reservoir project. The exterior color of fly ash is gray, and has some loose balls. The percent of SiO_2 and Al_2O_3 is high to 92% in fly ash, which illuminates it has high potential activity and small loss on ignition, and carbon content of fly ash is low shown by its gray exterior. The water demand of fly ash is low to 92.8%, and 45μm sieving residue is only 7.2%, which shows that fly ash is fine particles and majority is spherical. Scanning electron microscope photographs show clearly and validate the above analysis results. It shows this fly ash is an excellent first grade fly ash and has very good activity. The mix proportions of concrete are shown in Table 1.

Table1 The mix proportions of concrete

Serial Number	Water-cement ratio	F (%)	MgO (%)	Concrete materials dosage of per cubic meter (kg)									
				MgO	C	F	W	S	Gd	Gz	Gx	**A**	**B**
3R6	0.34	63	0	0	69	118	63	714	452	603	452	1.309	0
3R7	0.34	60	0	0	75	112	63	717	454	606	454	0.935	0
2R6	0.36	60	0	0	78	117	70	689	0	771	630	1.365	0.058
D1	0.48	35	1	2.42	157	85	117	645	573	430	430	1.452	0
D2	0.48	35	2	4.84	157	85	117	645	573	430	430	1.452	0
D3	0.48	35	3	7.26	157	85	117	645	573	430	430	1.452	0

A：Superplasticizer ； B：Air-entraining agent； C: Cement; F: Fly ash; S: Sand; W: Water

Best threshold selection: In general, the average of sequence point is selected as a threshold value to symbolize. For 100 observation data of specimen 2R6, first, every point of the original sequence is ranked by order from small to large, and then successive addition one percent of margin between the minimum and the maximum is the threshold. The complexity will change with the variety of threshold. It can be seen from fig.2 that the complexity of sequence has the maximum 0.766 when the threshold is -5.17×10^{-6}.

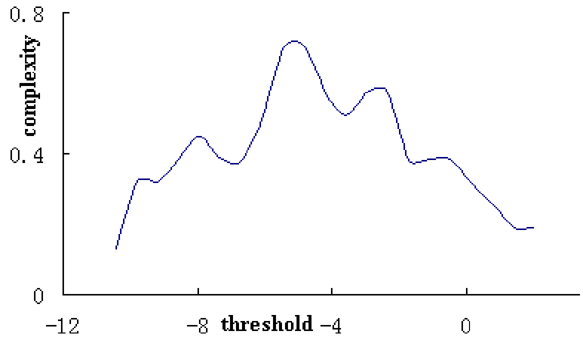


Fig. 2 The change of complexity with selected threshold value

The complexity of sequence is 0.574 when the threshold is the mean -4.18×10^{-6}, so it is not the best choice. The optimal threshold value should make the number of 01 equal or close.

Complexity calculation: As the actual observation conditions, observation sequence have shortcomings: observation time is not equal interval, furthermore, some observation interval is quit long. So the management should be taken to get equal interval. The approach is: the deterministic and stochastic methods are both used to add data, which is interpolation method and random or Logistic mapping.

Table 2: The complexity of RCC autogenous volume deformation

Serial Number	3R6		3R7		2R6		D1		D2		D3	
Age	180d	28d	180d	28d	180d	28d	180d	28d	180d	28d	180d	28d
Original	0.465	0.598	0.584	0.634	0.766	0.784	0.184	0.184	0.176	0.176	0.171	0.171
De-noising	0.346	0.413	0.358	0.424	0.447	0.475	0.184	0.184	0.176	0.176	0.171	0.171

Table3: Comparison on complexities at the different temperature

Number	3R6	2R6
20℃	0.346	0.447
30℃	0.483	0.562

Table 4: Comparison on complexities of using optimal threshold value and mean threshold value

Number	3R6	3R7	2R6	D1	D2	D3
Average	0.313	0.309	0.329	0.184	0.176	0.171
Optimal	0.346	0.323	0.447	0.184	0.176	0.171

First, the average of sequence is calculated, the one less than the average is marked with "0", and the one greater than the average is marked with "1", then the original sequence becomes the sequence of two symbols (0,1). Each specimen's complexity with wavelet de-noising can be calculated by the Lempel-Ziv algorithm. At the same time, the complexities without wavelet de-noising are calculated (Table 2).

From Table 2, we can see that the 2R6 complexity is largest, 3R6 and 3R7 take second place, D1, D2 and D3 are small obviously; the complexity with wavelet de-noising is less than original sequence and has evident law. From Table 3, the complexity of 30℃ is greater than the one of 20℃.

Compare between the average threshold and the optimal thresholds are shown in Table 4, although the average threshold can approximately express the different complexity, the law of change is less evidence than the optimal threshold.

RESULTS AND DISCUSSION

The influence of cement and fly ash, MgO content on the complexity are shown form Fig.3~5.

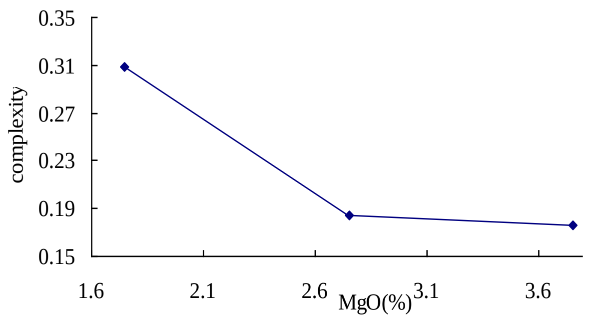
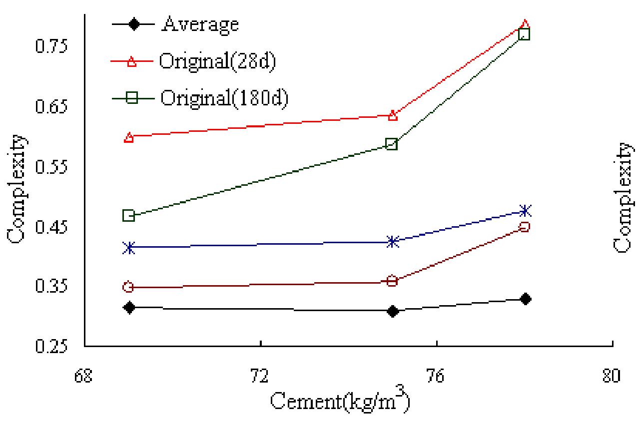


Fig. 3: The influence of MgO content on complexity

RCC autogenously volume deformation shows contraction usually, and it will expand if cementitious materials contain certain expansible ingredients. The content of MgO in cement is 1.5%, but for specimen 2R6, 3R6 and 3R7, content of fly ash in cement is greater than 60%, and the fly ash admixture can inhibit MgO to hydrate and expand. This is due to the decrease of cement paste porous structure and pore solution alkalinity by admixing with fly ash.



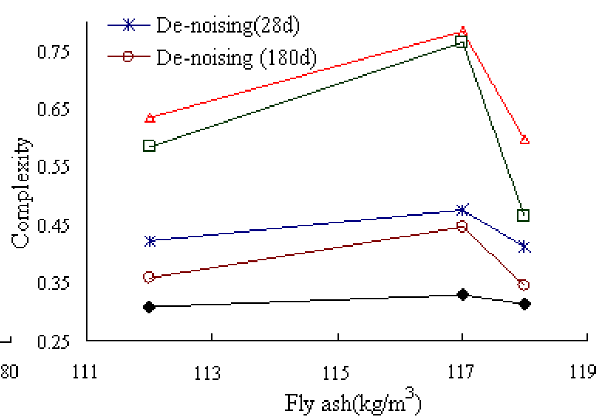


Fig.4: The influence of cement content on complexity **Fig. 5: The influence of fly ash content on complexity**

Microscopic study shows the alkalinity of MgO hydration environment accelerate the hydration and expansion of MgO, the existence of Hydroxide ion impact the distribution of magnesium ions around MgO granule, also affects the morphology, size and location of magnesium hydroxide crystal generated by MgO hydration. Magnesium hydroxide generated in high alkalinity is small crystals which are massive and short column and gather in the narrower area around MgO granule surface, these crystal make cement paste harden and expand largely. In low-alkali medium, magnesium hydroxide is big and coarse which are acicular or cylindrical and disperse in the wider area around MgO granule surface, some grow into the pore of cement paste, so there are little crystal which can effective expand, and cement paste have a small quantity of expansion[5].The autogenously volume deformation curves of specimen 2R6, 3R6 and 3R7 don't show obvious increase trend but display random; and the fly ash content of specimen D1, D2 and D3 is 35%, which is half of specimen 2R6, 3R6 and 3R7, MgO content is greater than the former, so the autogenously volume deformation curves of specimen D1, D2 and D3 show obvious increase trend. Thus, specimen 2R6, 3R6 and 3R7's complexity of autogenously volume deformation are evident greater than D1, D2 and D3's.

The autogenously volume deformation of RCC with a certain amount of fly ash increased along with cementitious materials augment. When cementitious material gross is certain, the autogenously volume deformation of RCC reduced along with fly ash augment, especially in early age. Because in RCC admixed a certain amount of fly ash, the product's structure around product generated by hydration of fly ash has high strength, these hydration products generated in late have less impact on autogenously volume deformation. Therefore, variations of concrete autogenously volume deformation reduced by admixing plentiful fly ash. Meanwhile, due to hydration of cement mainly occurred in early, degree of C_3S hydration is 70% in 28d age, C_3A is 84%, C_4AF is 74%, so the variations of autogenously volume deformation in this period is larger. It can be seen from table 4 that specimen 2R6, 3R6 and 3R7's complexity of autogenously volume deformation in early age are evident greater than the ones in 180d age. Specimen 2R6 complexity is bigger than 3R6 and 3R7, which is due to admixing a certain amount of air-entraining agent, so there are more pores. It makes autogenously volume deformation more complex and complexity increase.

It can be seen from table 4 that the complexity of the volume deformation is greater with the higher temperature. Because high temperature will accelerate hydration, and the change of hydration products is more complicated. Literature [6] shows the increase of temperature has the biggest impact on the hydration of C_2S; for C_3S, temperature impact on the hydration mostly in early age, and little in late. So the complexity is more complicated in early age.

CONCLUSION

By introducing Lempel-Ziv algorithm, the complex of deformation sequence is explored firstly, and gets meaningful results:
This method gives quantitative index through simple operation, and describes the complicacy of autogenously volume deformation effectively and feasible.

The observation of deformation contains noise and increase complexity. So the de-noising of deformation observation is necessary, and wavelet is an effective method for de-noising.

The study shows that: The deformation complexity of high volume fly-ash slag RCC is markedly larger than that of RCC mixed MgO. the deformation complexity of early age RCC is higher than that of 180d. The complexity is greater with the higher temperature. The deformation complexity of RCC mixed with air-entraining agent is greater.

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